N87-17639

THE VOYAGER ENCOUNTER WITH URANUS AND NEPTUNE

Ellis D. Miner
Jet Propulsion Laboratory, California Institute of Technology

Most of you have seen, I believe, the previews of coming attractions that were developed during the Saturn encounter to show the Uranus and Neptune encounter geometries. I would like to show the film clip again just to remind you of those geometries before I start discussions of what it is that we plan to do during the Uranus and Neptune encounters. Let's run the movie.

You notice that Voyager 2 approaches Uranus at a relatively low phase angle and high southerly latitude. Only when the spacecraft is very close to Uranus does the geometry change appreciably. Most of the important observations occur within six hours of closest approach. Voyager flies through an earth and solar occultation zone and leaves Uranus at a relatively high phase angle of about 145 degrees. We don't have much opportunity to look at the equatorial region of the planet.

At Neptune, on the other hand, the approach is more nearly equatorial (about 35 deg S lat). Voyager 2 will come much closer to Neptune than to any of the other gas giants as it skims within about 2000 km of Neptune's cloudtops. It will pass through earth and solar occultation zones at both Neptune and its satellite, Triton. Again, Voyager 2 will leave Neptune at about 35 deg S latitude. That completes the film clip.

The operational instrument complement aboard Voyager 2 has not changed since launch (see Table 1). However, there is one change in personnel. Robbie Vogt has found his duties as Provost of Caltech to be such that he cannot continue as Principal Investigator, so Ed Stone has been officially named the Cosmic Ray Principal Investigator for the Uranus and Neptune encounters. He'll carry a dual role as both Principal Investigator and Project Scientist.

DR. POLLACK: Does he argue with himself?

DR. MINER: He argues with himself on occasion. Actually, we've had notably little argument with the Cosmic Ray experiment, because it has almost no interaction with any of the other experiments. Ed's dual role works out pretty well.

Let me briefly recount the past and future Voyager encounters illustrated in Fig. 1. Voyager 1 completed its planetary mission with the Saturn encounter in November of 1980. It is leaving the solar system at an angle of about 35 degrees above the ecliptic plane. It will not come close to any of the other planets, but it is headed in approximately the direction of the incoming interstellar wind. Voyager 2, on the other hand, encounters Uranus on January 24, 1986, and will continue on to an August 1989 encounter with Neptune. The timing of the Neptune encounter has been changed slightly from our earlier plans. Voyager 2 will now arrive on August 25th at 0400 UT. Of course, it will be August 24 in the United States.

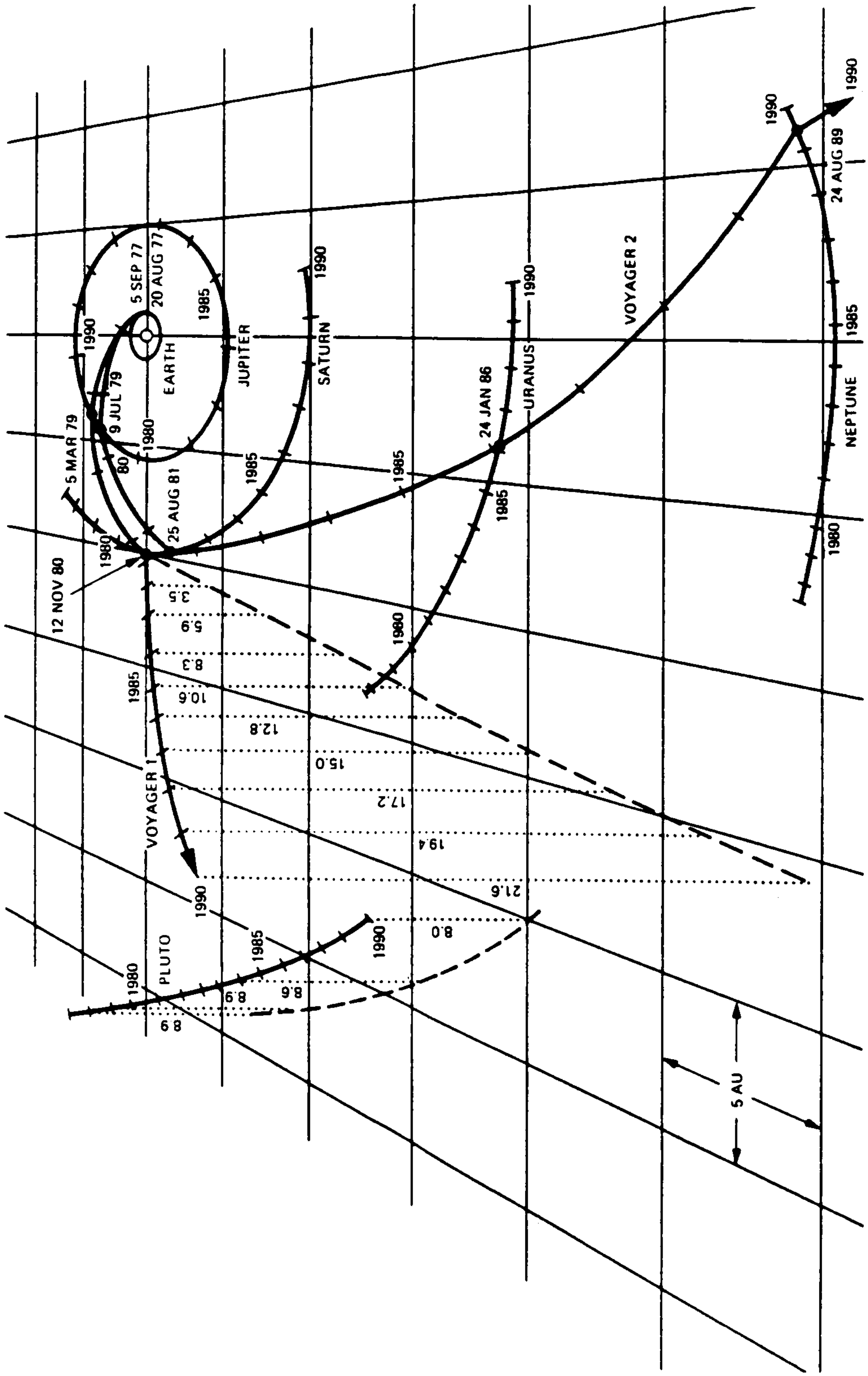

Figure 1. Interplanetary trajectories and planetary encounters of Voyagers 1 and 2

Table 1

Voyager Science Investigations

Investigation	Principal Investigator/Organization
Imaging Science	B. Smith, University of Arizona (Team Leader)
Infrared Spectroscopy and Radiometry	R. Hanel, Goddard Space Flight Center
Photopolarimetry	A. Lane, Jet Propulsion Laboratory
Ultraviolet Spectroscopy	L. Broadfoot, University of Arizona
Radio Science	L. Tyler, Stanford University (Team Leader)
Magnetic Fields	N. Ness, Goddard Space Flight Center
Plasma	H. Bridge, Massachusetts Institute of Technology
Plasma Wave	F. Scarf, TRW
Planetary Radio Astronomy	J. Warwick, Radiophysics, Inc.
Low-Energy Charged Particles	S. Krimigis, Johns Hopkins University
Cosmic Ray	E. Stone, California Institute of Technology

Small adjustments have been made to the trajectory of Voyager 2 at Uranus. The spacecraft is now following a path that will bring it within 29,000 km of Miranda. The best imaging will be done at a range of about 30,000 km. I will not say more about the satellite science planned for this encounter; nor will I talk about the ring science. I intend to spend the remainder of my time talking about those observations that have to do with the planet itself: either the atmospheric observations or those observations that provide information about the interior.

Voyager 2 will pass through an occultation zone that includes both Earth and Sun occultations. Within a couple of hours after Uranus closest approach, the spacecraft will enter the occultation zone at a rather oblique angle, resulting in a substantial difference in range between entrance and exit occultation measurements.

As the movie illustrated, the subspacecraft latitudes are near 70 deg S (IAU convention) during Voyager 2 approach. At 24 hours before closest approach the latitude is 69 deg S; 12 hours before closest approach the spacecraft is still 64 degrees south of the equator. By closest approach, Voyager 2 is 23 degrees north of the equator on the dark side. At +12 hours, we again see a very similar bulls-eye view, but this time of the dark side of the planet.

The trajectory at Neptune is still undergoing some discussion. Final decisions have not been made. The trajectory correction which adjusts the timing of the Neptune encounter occurs in mid-February of 1986, during the latter portions of the Uranus encounter. One remaining concern is that Voyager 2 will cross the equatorial plane inbound at approximately three Neptune radii. Of course, some of the recent measurements indicate that a ring (or arc) might be located at that distance from Neptune. We will be interested in receiving information on any ring parameters deduced from telescopic observations. It is possible that the trajectory will have to be revised to avoid potential damage to spacecraft instrumentation.

Voyager scientists have been planning for a 10,000 km miss at Triton. If we revert to the 40,000 km originally planned, Voyager 2 will cross Neptune's equator well outside the possible danger zone at three Neptune radii. If we don't have any problems with a ring at that distance, we can target for the 10,000 km miss distance at Triton that we hoped for.

DR. TAYLOR: What will be the criteria for trajectory selection? Can the decision be delayed?

DR. MINER: I think that much will depend on our estimates of the potential dangers at ring-plane crossing. The Triton encounter is of significant enough scientific importance that we do not want to chance damaging the spacecraft before we get to Triton.

The Neptune views from Voyager 2 are equatorial during approach. Because of the very close approach to Neptune the perspective doesn't change much until the spacecraft is very near the planet. Voyager 2 then flies over the north pole of Neptune. Incidentally, this will be the first time for any of the major planets that a spacecraft will fly over an auroral zone (if Neptune has an auroral zone). The fields and particles experiments are looking forward to that particular encounter with great enthusiasm. As the spacecraft recedes from the planet the illuminated south polar region will again be viewable; near-equatorial dark-side observations will also be possible.

As Voyager 2 approaches Uranus and Neptune we plan to do atmospheric dynamics observations, with narrow-angle imaging starting about 2,000 hours before closest approach and continuing until about 50 hours before closest approach. For Uranus, the cameras will see a planet rotating in the field of view with very little change in the latitude/longitude coverage. Voyager 2 will execute a series of time-lapse movies taken at intervals that correspond to improvements of a factor of 1.4 in resolution. Each of the movies is 36 hours in length, providing imaging coverage over two complete rotations of Uranus. These movies should enable imaging scientists to study atmospheric dynamics at a variety of scales. For Neptune, we revert to the class of atmospheric imaging that was done at Jupiter and Saturn; the spacecraft will obtain five-color imagery every 72 degrees of longitude, so that we can create zoom movies for Neptune similar to those created from Jupiter and Saturn imagery.

Near 10 days before and after closest approach to each planet the IRIS field of view is filled by the planet. Infrared observations of the planets at those times will provide two important pieces of information. Firstly, the IRIS data will determine the precise, disk-integrated temperature of both the illuminated and the unilluminated hemispheres. Secondly, the IRIS radiometer will measure the bolometric reflectivity of each planet on the illuminated side. Because of the unusual orientation of its rotation axis, Uranus can be expected to have a heat balance quite different from the other giant planets.

For Jupiter, Saturn and Neptune most of the incoming solar energy is absorbed at near-equatorial latitudes. At Uranus, most of the solar input is presently near the pole. Since the amount of energy is probably relatively constant with latitude for each of the gas giants, a different sort of energy transport is occurring at Uranus than was seen at Jupiter and Saturn, and than we expect to see at Neptune. The ratio of the total emitted energy to the absorbed energy from the Sun has been measured by Voyager at both Jupiter and Saturn, and both planets appear to have substantial internal heat sources. Uranus appears to have little or no internal heat source. One of the purposes of doing the infrared measurements discussed above is to measure (or set upper limits on) the internal heat from Uranus. The internal heat source within Neptune is probably even larger relative to solar input than it is at Saturn and Jupiter.

Some concern has been expressed about the low sensitivity of IRIS at Uranus and Neptune, whether it is capable of making the measurements that need to be made. In the thermal infrared there is really no difficulty; even with a single spectrum, obtained in 48 seconds, IRIS sensitivity is more than adequate. At longer wavenumbers, where the energy is from reflected solar radiation, there is a problem, and IRIS will probably need relatively long integrations in order to be able to determine the chemical composition of the atmosphere.

Accurate heat balance calculations require measurements of atmospheric brightness at different phase angles to determine the atmospheric phase functions for Uranus and Neptune. Figure 2 depicts the phase angle coverage planned for the Uranus encounter. The Photopolarimeter and the Wide-Angle Imaging Camera participate in each of these observations, which cover six different phase-angle ranges as indicated by the rectangles. The two curves in the figure represent phase angles at the center of the planet (lower line) and at the illuminated limb (upper line) as a function of encounter-relative time in hours.

The chemical composition of each of these atmospheres is of interest, particularly the abundances of He, C, N, and O relative to H. Table 2 summarizes the current knowledge. Measurements have been made for both Jupiter and Saturn, although the oxygen content in Saturn's atmosphere is still relatively unknown. For Uranus, there have been various estimates of the relative carbon abundance. We think nitrogen is somewhat underabundant, but we really know very little about either helium or oxygen abundances. Neptune's atmospheric composition is thought to be very similar to that of Uranus. Voyager 2 should provide relative abundances of H, He, C, and N. Oxygen will be more difficult to determine because of the low temperatures and the extreme depth of water ice clouds.

The IRIS, UVS, and Radio Science experiments will provide information on atmospheric temperatures from the microbar region down to 2 or 3 bars as illustrated by Fig. 3. At Uranus and Neptune, IRIS covers intermediate pressure levels, the Ultraviolet experiment overlaps IRIS somewhere in the upper portions of the Uranus and Neptune atmospheres, and the Radio Science experiment should extend the pressure-temperature profile down to several bars. At both planets there may be some opacity caused by methane clouds.

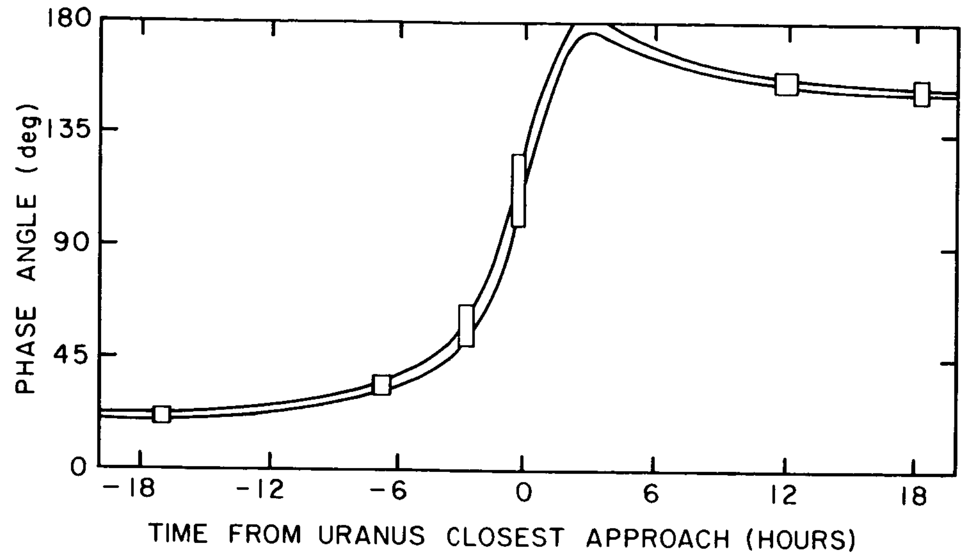

Figure 2. Phase angle coverage of Photopolarimeter and Wide-Angle Imaging Camera observations planned for the Uranus encounter. The six scheduled observation periods denoted by rectangles are shown along with the variation of phase angle of disk center (lower curve) and the illuminated limb (upper curve).

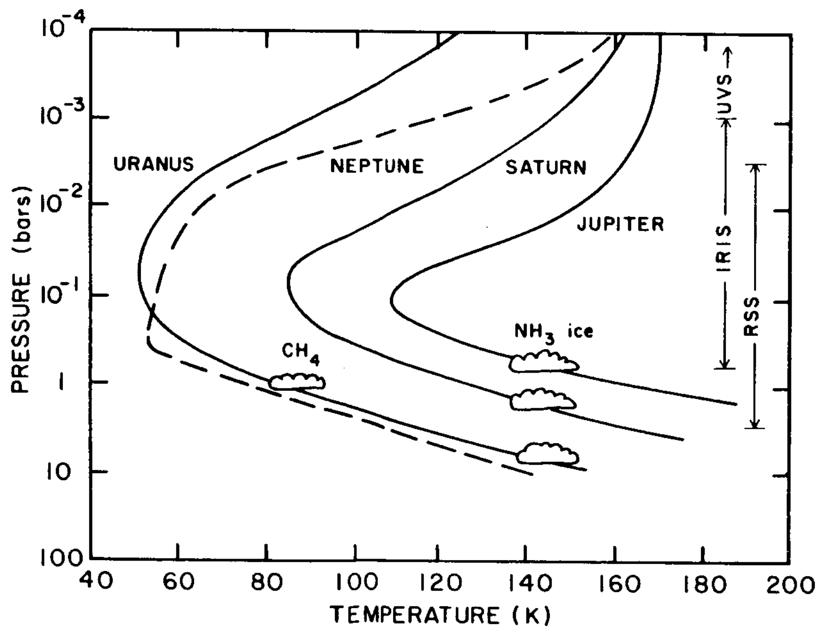

Figure 3. Vertical temperature profiles for the four giant planets and the respective range of vertical coverage by the IRIS, UVS and Radio Science experiments.

Table 2

Elemental Abundances for the Atmospheres of the Major Planets

Planet	Abundance Relative to Solar			
	He	C	N	O
Jupiter	0.87 ±0.18	2.32 ±0.18	1.0 ±0.5	≈0.03
Saturn	0.61 ±0.29	2.1 +1.6/−0.5	≈2.4	?
Uranus	?	1.3–4	<1	?
Neptune	?	0.3–16	<1	?

Radio Science experiments will include earth-based monitoring of the occultation of Voyager 2 by the planet between 2.5 and 4 hours after closest approach. Occultations of the spacecraft by the rings will also be monitored on both ingress and egress sides. We had hoped to be able to do an ultraviolet solar occultation experiment at both ingress and egress of the sun. Unfortunately, at solar egress the spacecraft is still being maneuvered to track the planetary limb for the Radio Science experiment. So we're limited to only an ingress measurement of solar occultation by the UV experiment. There are also two stellar occultations which will be observed using the Ultraviolet experiment; these provide data on the structure of the atmosphere near the polar regions. (The Radio Science and UVS Solar occultation observations are limited to equatorial measurements.) The UVS observes gamma Pegasi, both at ingress and egress, to get the south polar and north polar measurements. It will also observe a grazing occultation by nu Geminorum that will provide better altitude-resolution data for near-equatorial regions of the upper atmosphere.

The spacecraft trajectory for Neptune encounter results in an occultation of the spacecraft by the planet from about 10 minutes after closest approach until about 50 minutes after closest approach. Ingress is near the north pole; egress is slightly south of the equator. If there exists a ring (or arc) near three Neptune radii and it has particles that are centimeter size or larger, then we may observe their effect on the spacecraft radio signals near the time of closest approach to Neptune and again 1.5 hours later.

The internal composition of the planets is also of interest. Inferential information on the internal structure is provided in part by carefully tracking the spacecraft as it flies by the planets in order to determine the detailed characteristics of the planetary gravitational field. The relative mass distribution in the interior of the planet affects both the oblateness and the gravitational harmonic coefficients, so different models of the interior correspond to different allowed relations between oblateness and J_2. Thus, by comparing measurements of the optical oblateness obtained with the Imaging System to the J_2 gravitation harmonic term determined from Radio Science analysis, the range of acceptable interior models can be restricted.

Since the relationship between oblateness and J_2 depends on planetary rotation rate, an improved determination of the rotation period coupled with an accurate estimate of the oblateness and/or J_2 will be particularly useful for inferring internal structure.

Elliot and his co-workers have been able to determine J_2 for Uranus from ring measurements. Their estimated uncertainty of 5×10^{-6} is about six times better than the expected Voyager precision. However, Voyager Imaging and Radio Astronomy experiments should provide a direct determination of the rotation period to a precision far better than any of the present estimates.

For Neptune, the contribution by Voyager will be even stronger. Voyager measurements can improve by a factor of four the precision of J_2 compared to the current estimates. Again, the Imaging and Planetary Radio Astronomy experiments should tie down the Neptune body rotation period fairly well. The rotation period of Neptune has been estimated using ground-based photometry, but photometry is not always reliable. Data from 1980 indicate a reasonably well-defined period on the order of 18 hours, but observations just a year later reveal no clear periodicity.

DR. INGERSOLL: That may not be the observer's fault. It may be that the photometry is simply reflecting changes in the cloud features.

DR. MINER: That's very true. I wasn't implying that the observers didn't use proper techniques. For Neptune sequence development, we are planning to use a period of 17.8 hours, which is consistent with the recent photometry and CCD imaging estimates. However, note that present determinations of J_2 and optical oblateness imply a period of 13.7 hours. It is possible that the recent CCD and photometric measurements are overly influenced by rapid cloud motions and may not measure the true body rotation rate.

Also of interest for internal composition of the planets are the magnetic field measurements. The current estimate of the Uranus magnetic field is based on the Lyman alpha flux. IUE observations show an excess of about a kilorayleigh of Lyman alpha radiation coming from Uranus. IUE observers interpreted this Lyman alpha emission as auroral activity, which implied that Uranus possesses a magnetic field. The estimated intensity of Lyman alpha radiation from Uranus corresponds to 0.5 to 3×10^{12} W of power in such an auroral emission. Only an upper limit exists for possible auroral emissions from Neptune. Based on thse estimates, Voyager scientists predict that if the planet possesses an iron core, Voyager 2 should encounter the magnetopause between 9 and 19 Uranus radii. For Neptune, the number would be in the range of 10-22 Neptune radii. If an ice layer is the source of the magnetic field, then the numbers would be somewhat larger. So, for example, we would expect Voyager 2 to encounter the Uranian magnetopause somewhere around 20 hours before closest approach; the outbound magnetopause probably would occur several days after closest approach.

Voyager 2's closest penetration into the magnetic field at Uranus occurs fairly near the time of closest approach of the planet. Voyager 2 will penetrate the field down to an L-shell of just under 4.5. Miranda's orbit is at an L-shell of 5.1; Voyager would cross that L-shell about an hour before closest approach and again near the moment of closest approach. The known rings are well inside the spacecraft trajectory. At Neptune the spacecraft goes very near the pole of magnetic field space (assuming the magnetic field is aligned with the rotation axis). Field penetration is down to a minimum L-shell of 2.45 Neptune radii inbound; outbound it will be a little further out. That summarizes the Voyager atmospheric investigations of Uranus and Neptune.

DR. BELTON: I was just wondering, does this ring around Neptune really exist? I haven't seen anything. What's the story?

DR. HUBBARD: Yes, the ring really does exist, except that it's not a complete ring. The information suggests that 90 percent of the time we're in no danger of getting an occultation from the ring; so 90 percent of the time it isn't there. Whether it's intermittent in time or space, we don't know at the moment. We had a very clean detection last year.

DR. ALLISON: Ever since Monday afternoon I've been wanting to make a remark which I'm finally going to offer now, because I think it's relevant to this session. We've all been impressed by the work of Gordon Bjoraker on the five micron data and its implication of low water abundance at the IR sounding level on Jupiter. I think it's important to remember (and Bill Rossow could say this better than I can) that if Jupiter has a strongly water-enriched atmosphere, then condensation will occur at deeper levels than predicted by the canonical models. One can imagine dynamical and microphysical processes which would deplete the saturation vapor curve above the cloud condensation level where we have infrared data. And yet there could still be a massive water cloud at deeper levels in Jupiter's atmosphere. Since this is a session on future space flight opportunities, I just want to say that I hope Hasso Niemann will still do everything possible to calibrate the Galileo Probe neutral mass spectrometer for water. It's been said that the purpose of the Galileo mission is to measure the water abundance on Jupiter. Although that's probably an exaggeration, I think that it is an extremely important measurement for us to keep in mind.